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A Study of Some Non-Random Aspects of the Frequency of
Meteorite Falls

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Abstract

A statistical study has been made of some of the non-random aspects of the frequency of meteorite fall as a function of time. In the interval of 1 - 1000 days, non-random assemblages have been found at periods other than one day and one year, together with integer multiples thereof. Although it is possible that some of the assumed periods are "real" in the sense that they have physical significance, the statistics make this appear unlikely.

The least random assemblage in the neighborhood of one-year does not occur at exactly one year (365.24 days). Instead there appear to be two particularly non-random assemblages, the first at about 364.46 days and the second at 366.1 days. The latter appears to be linked with the high-iron chondrites. The reasons for this curious behavior are unknown.

Histograms showing the number of falls which have been observed during specific times of the year, dividing the year into 20 equal parts, indicate a maximum in late January due to low-iron chondrites, one in mid-May due to high iron chondrites and one in late August and early September resulting from low-iron chondrites. The relative frequencies of the groups appear to change with time.

Indications of "clustering" of meteorites in orbit have been obtained by plotting the time of fall during a year against the time of fall in a period consisting of an integer number of years. Marked clustering is noticeable in the high-iron chondrites as well as in the veined-hypersthene chondrites on a five-year period.

As an example of a cultural effect upon the observed rate of meteorite fall, it has been found that in Western Europe and in North America, which are predominantly Christian regions, observed daytime falls on Sundays are about 30% lower than average and nearly 40% lower than the average excluding Sundays. Although this difference is appreciable, it is surprisingly small.

The accumulated evidence strongly suggests that the non-randomness of the observed rate of fall of meteorites as a function of time of year is due primarily to astronomical factors rather than to cultural ones.

1. Introduction

It has long been recognized that with respect to two time-periods, observed rates of meteorite fall are non-random. First, with respect to the local time of fall, there is a pronounced diurnal effect. Meteorites are observed to fall most frequently between 15^h and 16^h local time and least frequently during the first three hours of the day. Second, there is a pronounced seasonal variation in the observed rate of fall, with the frequency being greatest in May and June and least in February and March. These facts have been reviewed by KRINOV (1960) and by MASON (1962).

It is clear that at least a part of these observed variations result from social effects. Farmers work in the fields during the day and sleep at night. More work is done outdoors during the summer than during the winter. It is possible, however, that some of these variations may have physical causes.

MILLARD and BROWN (1963), who examined the yearly and monthly time of fall patterns for departures from randomness, have pointed out that the histogram of falls per decade as a function of time contains at least three peaks together with a sharp decrease in the observed rate of fall after 1940 which they believe reflects an actual decrease in the rate of influx of meteorites. In addition, the observed monthly fall pattern for the veined-olivine-hypersthene chondrites was shown to depart substantially from randomness.

This investigation represents an attempt to explore these non-random aspects of the frequency of meteorite falls in greater detail than has thus far been attempted. Being that it is also possible that there might be non-random rates of fall for discrete periods other than the obvious ones of one day and one year, the investigation has been extended to survey the degree of non-randomness of the frequency of meteorite falls with respect to a number of arbitrary time-periods.

II. Procedure

The following procedure was used in the analysis:

1. A list of 526 well authenticated meteorite falls was compiled.

The sources used were mainly the Catalogue of Meteorites by PRIOR and HEY (1953), Principles of Meteoritics by KRINOV (1960) and KRINOV'S Meteoritical Bulletin (1957-).

Some of the data concerning Japanese meteorite falls were amended and corrected on the basis of information provided by Dr. Sadao Murayama (1962) of the National Science Museum in Tokyo.

The local time of fall of all the meteorites included in this list was known with an accuracy of at least ± 30 min. (± 0.021 day).

2. All the dates of falls were reduced to Greenwich Mean Time and expressed as Julian Days* (accuracy ± 0.02 days).

3. A coded IBM card was punched for each meteorite. Each card contained the following information: assigned code number of meteorite, year, month, day and hour of fall (local time) and the corresponding Julian Day + fraction G.M.T.

* The dates are indicated by the total number of days which have elapsed since January 1, 4713 B.C., 0 hour being noon rather than midnight.

4. The randomness of distribution of the dates of fall with respect to periods from 1 to 1000 days was tested by applying the χ^2 test. To perform this test a computer program was set up, according to which each Julian Day number, representing the date of fall, was divided by the number representing the period being tested. The answer included three significant figures to the right of the decimal point. The integral part of this result was then discarded and only the decimal fraction was used for the χ^2 computation. In a physical sense such a fraction represents the time of fall of a particular meteorite expressed as a fraction of a particular assumed period - e.g., if the Julian Day of a fall is 2,343,792.20 and the period being tested is 500 days, then $\frac{2,343,792.20}{500} = 4687.5844$ (or 4687 with a remainder of 292.20 days). In other words, this meteorite fell on the 293rd day of the 500-day period, which corresponds to 0.5844 of the period.

All the fractions obtained in the above step were then grouped into 20 cells: 0.000 - 0.0499, 0.050 - 0.0999, 0.100 - 0.1499 etc.

The number of meteorites in each group was counted and χ^2 for the distribution was calculated according to the formula

$$\chi^2 = \sum_{i=1}^k \frac{(o_i - e_i)^2}{e_i},$$

where k is the number of cells, o_i - the number of data in the i^{th} cell, e_i is the average number of data per cell ($e_i = \frac{n}{k}$), and n represents the number of falls used in the calculation.

The corresponding probability of randomness for each χ^2 value thus obtained was then calculated.

For comparison, a series of 526 random numbers was generated by the method described by Joel N. Franklin (1962), and the identical operations were performed with these numbers.

III. Comparison of Meteorite Falls with Random Numbers

χ^2 is shown in Figures 1 - 5 for assumed periods of integer numbers ranging from 1 to 1000 days.

As was expected the χ^2 for 365 days is high. Somewhat surprisingly the χ^2 for 1 day (in terms of GMT rather than local time) is also high. This latter non-random distribution apparently results from the combination of diurnal effect, with respect to local time, with highly localized geographic concentrations of observed falls. Most falls have been observed in Western Europe, with North America and India contributing smaller but nevertheless substantial numbers. The intermediate longitudes are sparsely represented.

Table I gives a summary of the number of assumed periods (or divisors) which give rise to distributions which possess less than or greater than a given probability of randomness. It can be seen that the pattern of observed fall of meteorites is indeed considerably less random than that of the random numbers. Confining our discussion to those probabilities of randomness which are less than 0.01, we see that the meteorites in the range of 1 - 1000 days give rise to 22 highly non-random assemblages, while the random numbers give rise to but 14.

The integer periods which give rise to assemblages having probabilities of randomness which are less than 0.01 are listed in Table II.

It is well-known that if an assemblage is non-random in relation to a specific period, it will probably be non-random with respect to integer multiples or divisors of that period, with the effect lessening as the multiples or divisors become larger. Thus it is not surprising that the assemblages for 182 days ($\frac{1}{2}$ year) and for 731-732 days (2 years) are also non-random. Similarly, the distribution for a period of one day is highly non-random, as are the distributions for 2, 3, 4, 6 and 7 days. This effect appears to be thoroughly damped by the end of 9 or 10 days.

The peak at 119 days is very close to $1/3$ year. This leaves the following peaks which are not obviously related to that of one year: 34, 219, 273, 439, 527, 546, 658, 703 and 864 days. Those at 219, 439 and 658 days may well be related to each other, as might those at 273 and 546 days.

When we subtract those peaks which can clearly be related to the non-random effects at 1 day and 1 year from the total number of assemblages having probabilities of randomness less than 0.01, the total number of such high peaks is reduced from 22 to 12, a number comensurate with that of the random numbers. Thus, although it is possible that some of the periods which give rise to non-random assemblages are "real" in the sense that they have physical significance, the statistics make this appear unlikely.

IV. More Detailed Study of Specific Periods

The time interval in the neighborhood of one year was subjected to a more detailed analysis. χ^2 's were computed in this region for each 0.1 day in order to observe the fine structure. In addition, the influence of certain types of meteorites upon the degree of non-randomness was examined.

Of the 526 meteorites in the assemblage, 80 were known with a high degree of confidence to be "high-iron" chondrites while an additional 134 were known to be "low-iron" chondrites. Thus 214 chondrites appeared to be well-classified. An additional 169 meteorites were known confidently to be chondrites, giving a total of 383 known chondrites in the assemblage. The balance of the assemblage (143 meteorites) consisted of irons, achondrites and unclassified stones.

In the region 350-380 days detailed χ^2 computations were made for the following assemblages: a) all falls (526), b) all chondrites (383), c) high iron plus low iron chondrites (214), d) low irons (134) and e) high irons (80). The results are plotted in Figures 6-10.

The most surprising feature of Figure 6 is that the least random assemblage does not occur at exactly one year (365.24 days). Instead, there appear to be two peaks, the first at about 364.6 days and the second at 366.1 days. In the plot for all chondrites (Figure 7) the first peak is shifted to 364.8 days while the second remains at 366.1 days. In both curves there are also indications of a peak at about 367.4 days. Figures 8, 9 and 10 indicate that the low iron chondrites contribute little, if anything, to any of the peaks, while the high iron chondrites contribute substantially to the peak at 366.1 days.

The reasons for this curious behavior, particularly of the high iron chondrites, are obscure. One is inclined to dismiss the effect as a random fluctuation superimposed upon the already high degree of non-randomness associated with a 365.24 day cycle. Nevertheless the magnitude of the fluctuation and its consistency give reason to suspect that an important effect is present in the data.

V. Distribution of Meteorite Falls Throughout the Year

A histogram showing the number of falls which have been observed during specific times of the year, dividing the year into 20 equal parts, is shown in Figure 11. Also shown in this figure is the conventional histogram which shows the rate of fall as a function of month. It can be seen that the division of the year into a number of units considerably greater than 12 brings out detail which is not apparent in the conventional seasonal plot. The probability of randomness of this distribution is less than 0.003.

Corresponding histograms for chondrites alone and for the low iron and high iron chondrites are shown in Figure 12. The persistence of certain maxima and minima suggest that the non-randomness results, at least in part, from physical factors, as distinct from cultural and climatic ones. The peak in the neighborhood of 0.1 (late January) appears to be the result of a

substantial contribution of low iron chondrites. The maximum between 0.35 and 0.40 (mid-May) appears to result from a contribution of high iron chondrites, while that between 0.65 and 0.70 (late August and early September) appears to result largely from a contribution of low iron chondrites.

In order to investigate changes in fall patterns as a function of time, the falls were listed in chronological order and divided into three groups containing equal numbers of meteorites: a) December 1704 - January 1869, b) January 1869 - February 1918, c) February 1918 - August 1961. The frequency of fall as a function of time of year was plotted for each group, with results shown in Figure 13. It can be seen that certain maxima and minima appear to persist for two or more of the time intervals, fortifying the view that there are preferential times of fall and that these can change with time.

VI. Periods of Integer Numbers of Years

The existence of preferential times of fall during the year would indicate that the Earth's orbit cuts the orbits of discrete meteorite streams at specific locations. Within a given stream matter could be spread out, at one extreme, over the entire orbit. At the other extreme matter could be concentrated into a clump in which the individual fragments would have approximately the same period and would follow nearly the same orbit. In the former case the fall in any one year would be about as probable as in any other until the sweeping effects and perturbation would result in a cessation of falls from that particular group. In the latter (clumping) case, by contrast, falls would take place at times separated by discrete integer numbers of years, the exact number depending upon the ratio of the period of the meteorite clump to that of the Earth.

Figure 14 shows χ^2 and the probability of randomness for the complete assemblage of meteorite falls as a function of assumed periods of integer numbers of years up to 20 years. Figures 15 and 16 show the probabilities broken down by chondritic type. It can be seen that there is a strong odd-even relationship, with probabilities of randomness of the assemblages being generally less in the odd yearly intervals than in the even ones.

It is possible to obtain indications of "clumping" by plotting the time of fall during a year against the time of fall in a period consisting of an integer number of years. When this is done, the five year period stands out as giving rise to a particularly non-random distribution, although other integer-year periods show indications of non-randomness as well.

Figure 17 shows the times of fall within a one-year period plotted against the times of fall within a five-year period.* The points lie on five parallel lines, but statistical tests indicate strongly a lack of randomness. Pronounced clumping appears to exist.

Figure 18 is a similar plot but limited to the high-iron chondrites. In certain regions clumping appears to be marked. The plot for low iron chondrites shown in Figure 19 indicates less marked clustering, but it is nevertheless suggestive. When the veined hypersthene (low-iron) chondrites are plotted by themselves (see Figure 20), non-randomness is particularly marked. Of note is the group of falls lying between 0.47 and 0.64 on the one-year period and between 0.09 and 0.13 on the five-year period. This represents a series of six falls between 1843 and 1903 at intervals which are almost exactly multiples of five years, all of them between late June and early August and all of them nearly identical chemically.

Clearly a detailed search for possible clusters in other combinations of periods is indicated.

* The scale of the one year axis for figures 17, 18, 19 and 20 differs from that in earlier figures. In figures 11, 12 and 13, January 1 is denoted by 0.0. In figures 17, 18, 19 and 20, January 1 is denoted by 0.15.

VII. Cultural Effects

It has generally been assumed that the cultural influence upon the lack of randomness of the frequency of observed fall as a function of time of year is a large one. The results in this paper suggest rather strongly that physical considerations are even more important.

We can obtain some idea of the importance of cultural effects upon the observed rates of meteorite fall by examining the number of daytime falls in North America and in Europe west of the Ural Mountains as a function of the day of the week. These areas being predominantly Christian ones should show fewer observed falls on Sundays for the reason that farmers generally will not have been working in the fields.

The results tabulated in Table III indicate this to be correct. Observed daytime falls on Sundays are 31% lower than average and 38% lower than the average excluding Sunday.

Thus, although a pronounced cultural effect is apparent, considering the great difference in the behavior of rural people on Sundays (and to a lesser extent on Saturdays) compared with other days of the week, the differences are surprisingly small. One would not expect seasonal effects to be as great as this on a purely cultural basis, yet the observed fluctuations shown in Figures 11 - 13 show fluctuations as a function of time of year which are considerably greater than 40%.

Again, the evidence strongly suggests that the non-randomness of the observed rate of fall of meteorites as a function of time of year is due primarily to astronomical factors rather than to cultural ones. The latter are probably present and are probably measurable but the primary influences appear to be physical ones.

TABLE I

The Probability of Randomness of Meteorite Falls
Compared with Random Numbers

526 RANDOM NUMBERS			526 METEORITE FALLS		
p	Assumed Periods	Number	p	Assumed Periods	Number
<0.01	1 - 200	3	<0.01	1 - 200	9
	201 - 400	6		201 - 400	4
	401 - 600	1		401 - 600	3
	601 - 800	3		601 - 800	5
	801 - 1000	1		801 - 1000	1
		<u>14</u>			<u>22</u>
<0.05	1 - 200	11	<0.05	1 - 200	21
	201 - 400	9		201 - 400	19
	401 - 600	9		401 - 600	8
	601 - 800	7		601 - 800	11
	801 - 1000	5		801 - 1000	14
		<u>41</u>			<u>73</u>
<0.50	1 - 200	99	<0.50	1 - 200	114
	201 - 400	99		201 - 400	108
	401 - 600	85		401 - 600	91
	601 - 800	104		601 - 800	99
	801 - 1000	93		801 - 1000	102
		<u>480</u>			<u>514</u>
>0.50	1 - 200	101	>0.50	1 - 200	86
	201 - 400	101		201 - 400	92
	401 - 600	115		401 - 600	109
	601 - 800	96		601 - 800	101
	801 - 1000	107		801 - 1000	98
		<u>520</u>			<u>486</u>

TABLE II

Integer Periods Giving Rise to Assemblages Which Have
Probabilities of Randomness ≤ 0.01

<u>Assumed Period</u>	<u>Probable Cause</u>	<u>Assumed Period</u>	<u>Cause</u>
1	1 day	364	1 year
2	2 x 1 day	365	
3	3 x 1 day	439	2 x 219 days?
4	4 x 1 day	527	?
6	6 x 1 day	546	2 x 273 days?
7	7 x 1 day	657	3 x 219 days?
34	?	658	
119	1/3 x 1 year?	703	?
182	1/2 x 1 year	731	2 x 1 year
219	?	732	
273	?	864	

TABLE III

Observed Falls Occurring Between 6:00 A.M. and 8:00 P.M.
As a Function of the Day of the Week

<u>NUMBER OF OBSERVED FALLS</u>			
<u>Day</u>	<u>Europe West of Urals</u>	<u>North America</u>	<u>Total</u>
Monday	22	5	27
Tuesday	29	12	41
Wednesday	22	14	36
Thursday	21	8	29
Friday	32	11	43
Saturday	20	6	26
Sunday	<u>16</u>	<u>5</u>	<u>21</u>
	162	61	223

References

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Figure Captions

- Figure 1. The Probability of Randomness of Assemblage of Times of Fall of 526 Meteorites with Respect to Arbitrary Periods
1 day - 200 days
- Figure 2. The Probability of Randomness of Assemblage of Times of Fall of 526 Meteorites with Respect to Arbitrary Periods
200 - 400 days
- Figure 3. The Probability of Randomness of Assemblage of Times of Fall of 526 Meteorites with Respect to Arbitrary Periods
400 - 600 days
- Figure 4. The Probability of Randomness of Assemblage of Times of Fall of 526 Meteorites with Respect to Arbitrary Periods
600 - 800 days
- Figure 5. The Probability of Randomness of Assemblage of Times of Fall of 526 Meteorites with Respect to Arbitrary Periods
800 - 1000 days
- Figure 6. The Probability of Randomness of Assemblage of Times of Fall of 526 Meteorites with Respect to Periods
350 - 380 days
- Figure 7. The Probability of Randomness of Assemblage of Times of Fall of 383 Chondrites with Respect to Periods
350 - 380 days
- Figure 8. The Probability of Randomness of Assemblage of Times of Fall of 214 High Iron and Low Iron Chondrites with Respect to Periods
350 - 380 days
- Figure 9. The Probability of Randomness of Assemblage of Times of Fall of 134 Low Iron Chondrites with Respect to Periods
350 - 380 days
- Figure 10. The Probability of Randomness of Assemblage of Times of Fall of 80 High Iron Chondrites with Respect to Periods
350 - 380 days
- Figure 11. The Distribution of 526 Falls
- Figure 12. The Distribution of Falls of Different Types of Meteorites
(by 1/20 of year)
- Figure 13. The Frequency of Fall as a Function of Time of Year
- Figure 14. The Probability of Randomness of Assemblage of Times of Fall of 526 Meteorites with Respect to Periods
1 year - 20 years
- Figure 15. The Probability of Randomness of Assemblage of Times of Fall of 80 High Iron Chondrites with Respect to Periods
1 year - 20 years

- Figure 16. The Probability of Randomness of Assemblage of Times of Fall of 134 Low Iron Chondrites with Respect to Periods
1 year - 20 years
- Figure 17. The Distribution of 526 Falls with Respect to One-Year Period, Versus Their Distribution with Respect to Five-Year Period
- Figure 18. The Distribution of 80 High Iron Chondrites with Respect to One-Year Period, Versus Their Distribution with Respect to Five-Year Period
- Figure 19. The Distribution of 137 Low Iron Chondrites with Respect to One-Year Period, Versus Their Distribution with Respect to Five-Year Period
- Figure 20. The Distribution of 39 Veined Hypersthene Chondrites with Respect to One-Year Period, Versus Their Distribution with Respect to Five-Year Period

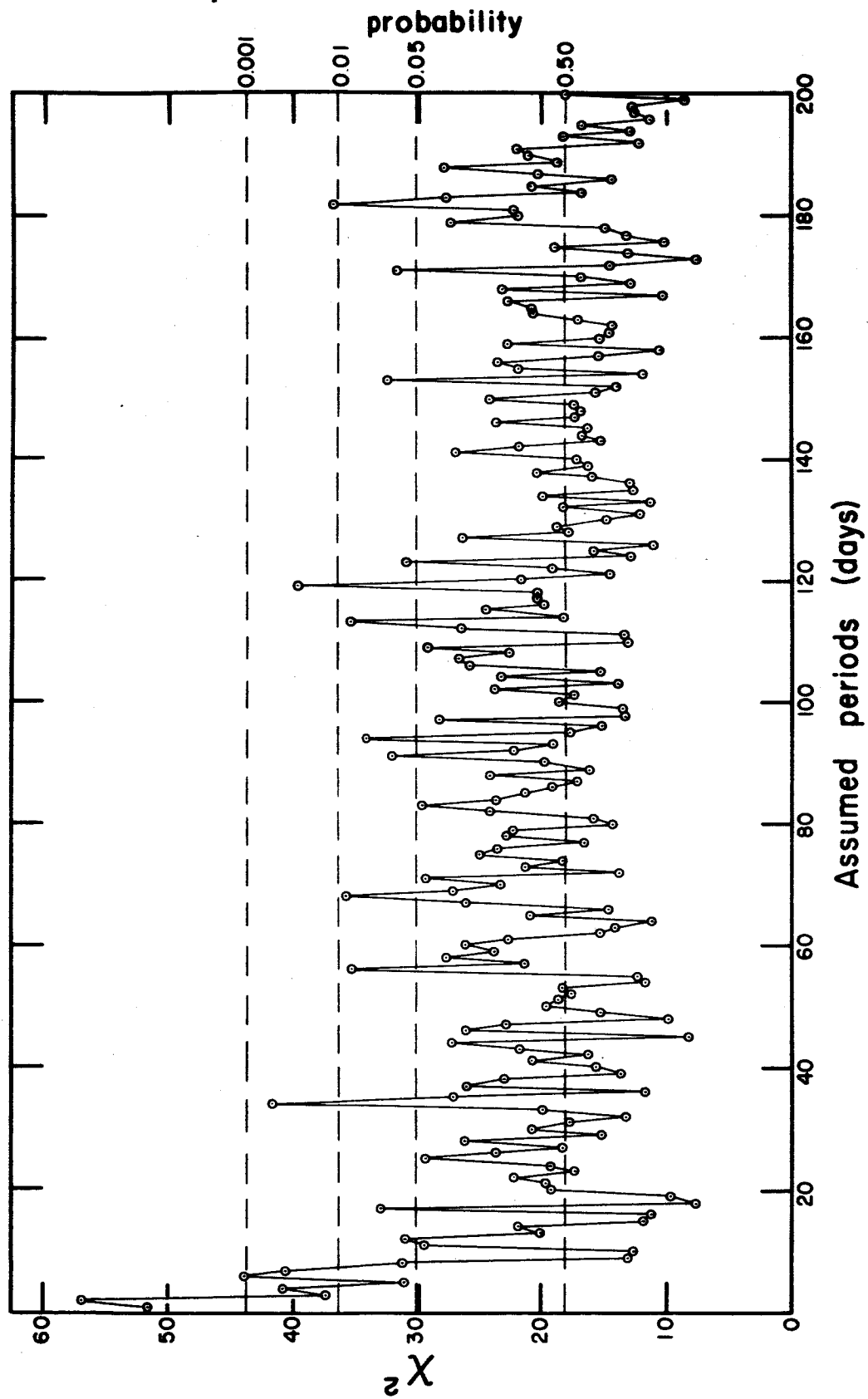


Figure 1

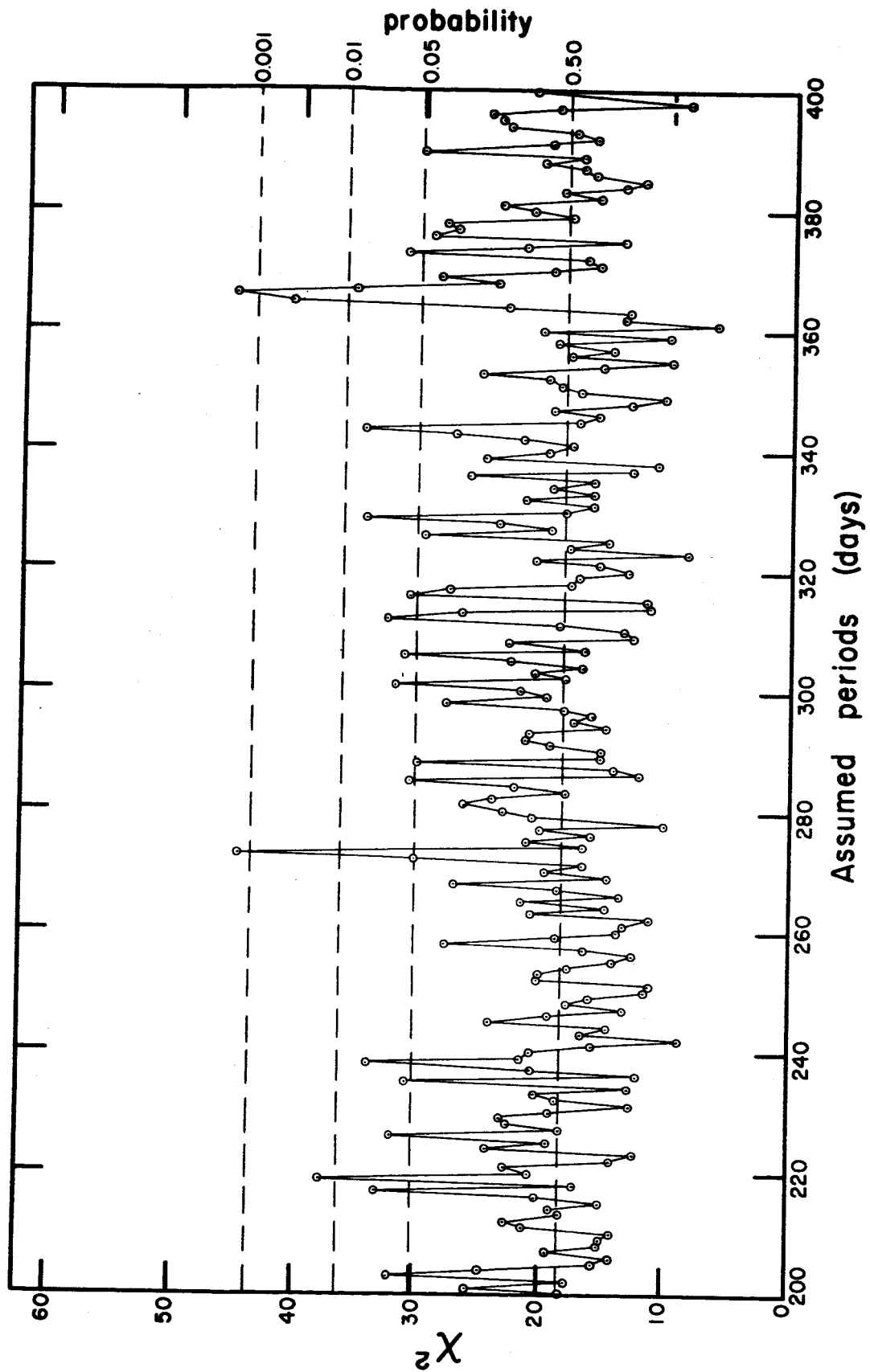


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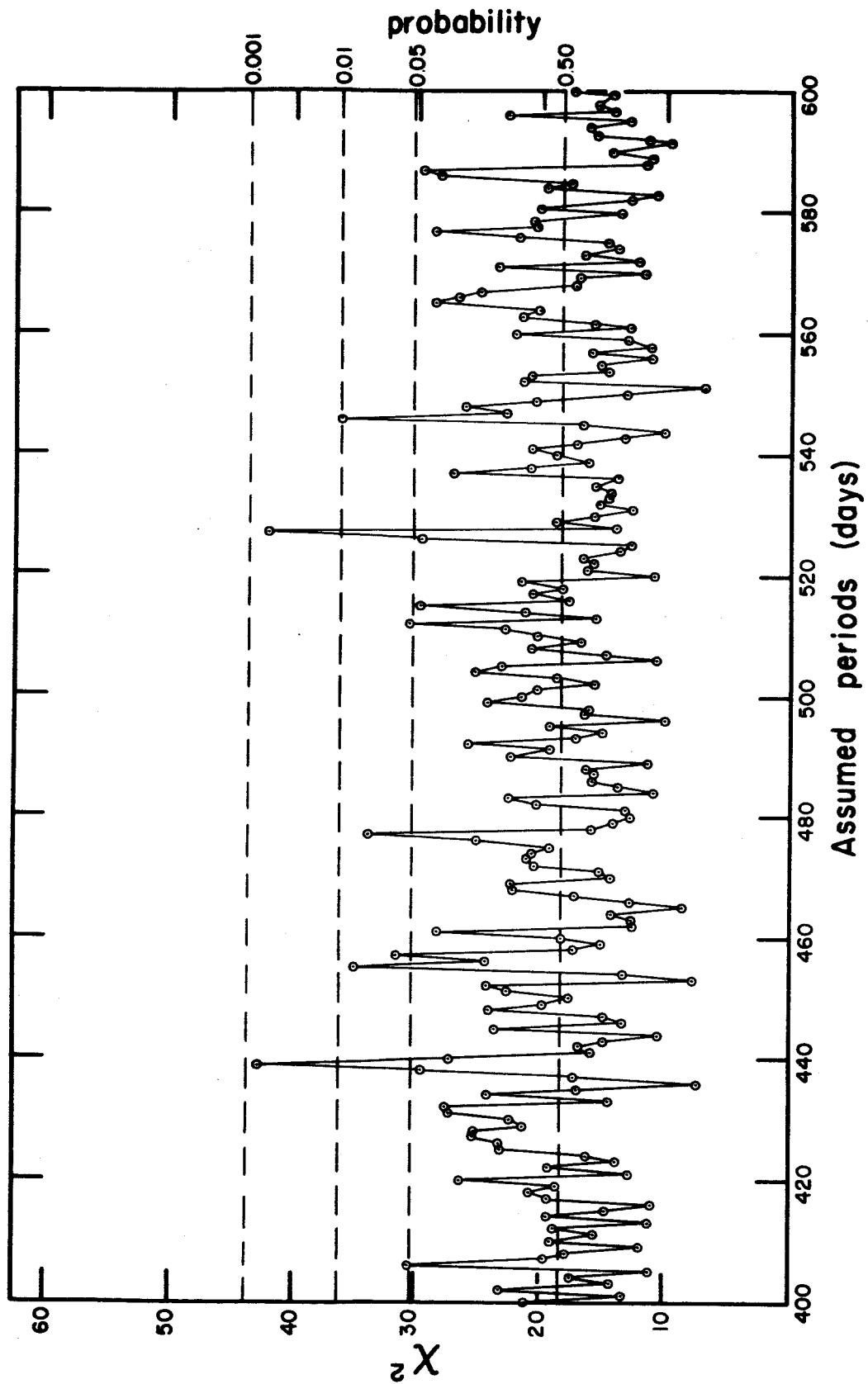


Figure 3

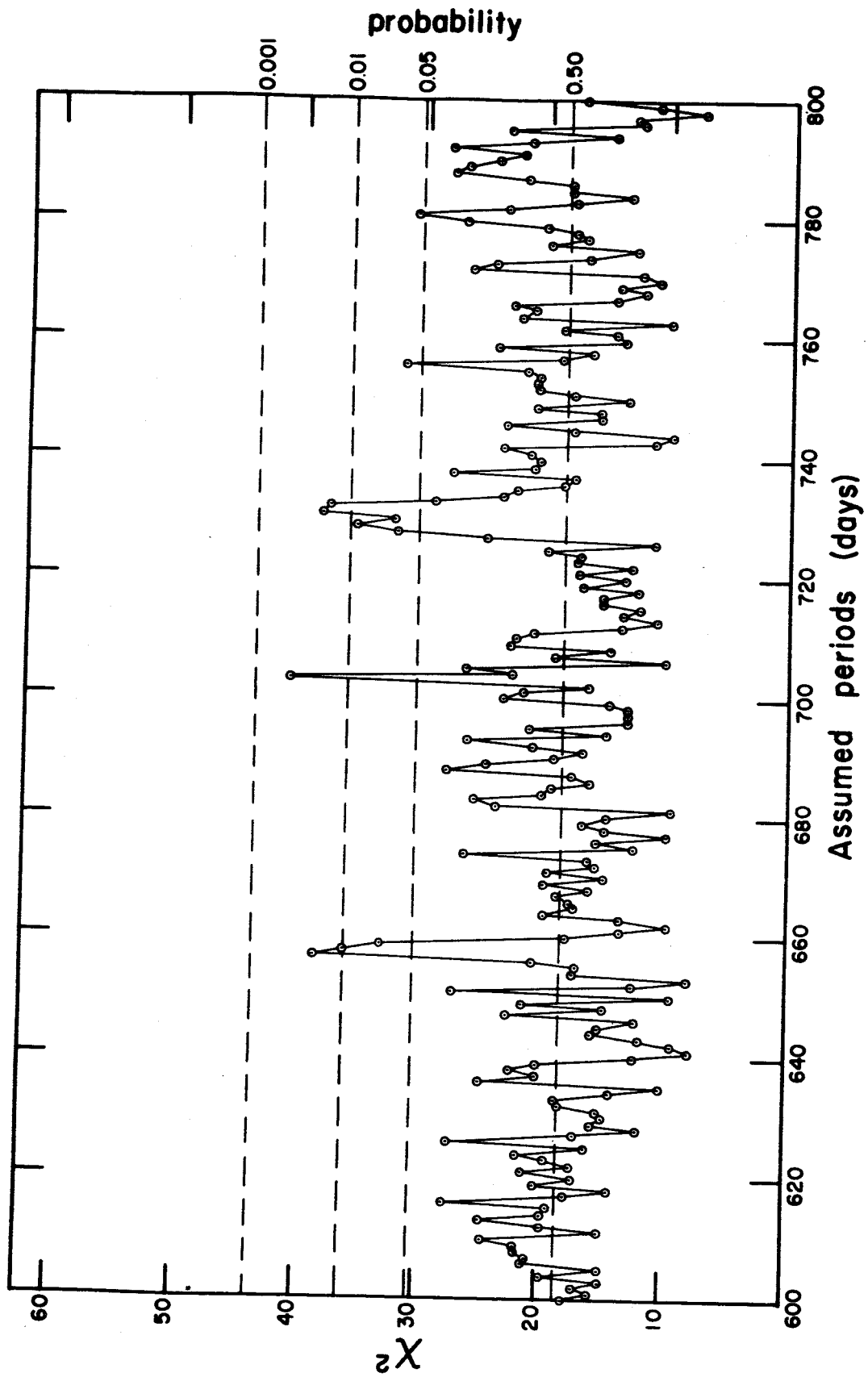


Figure 4

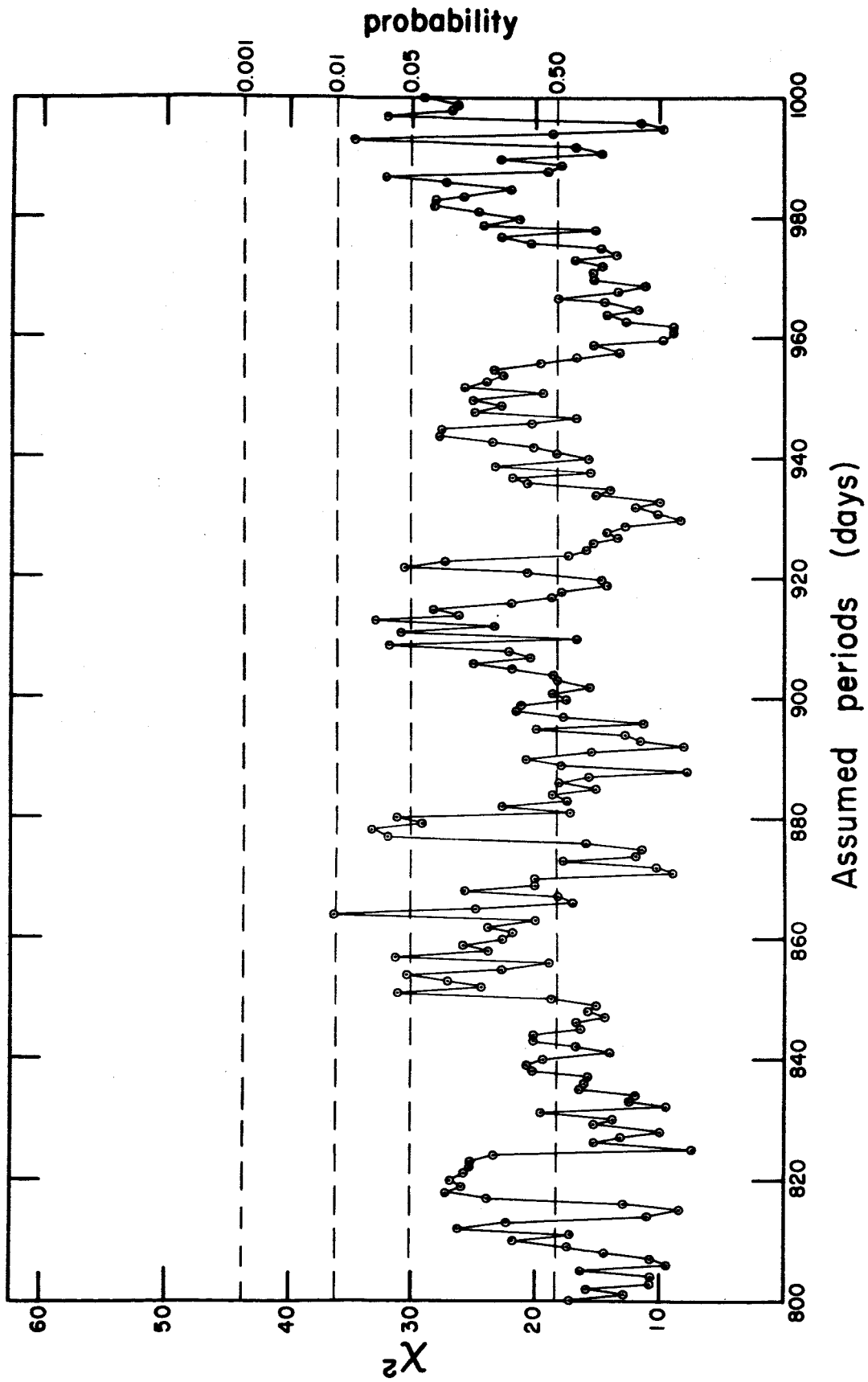


Figure 5

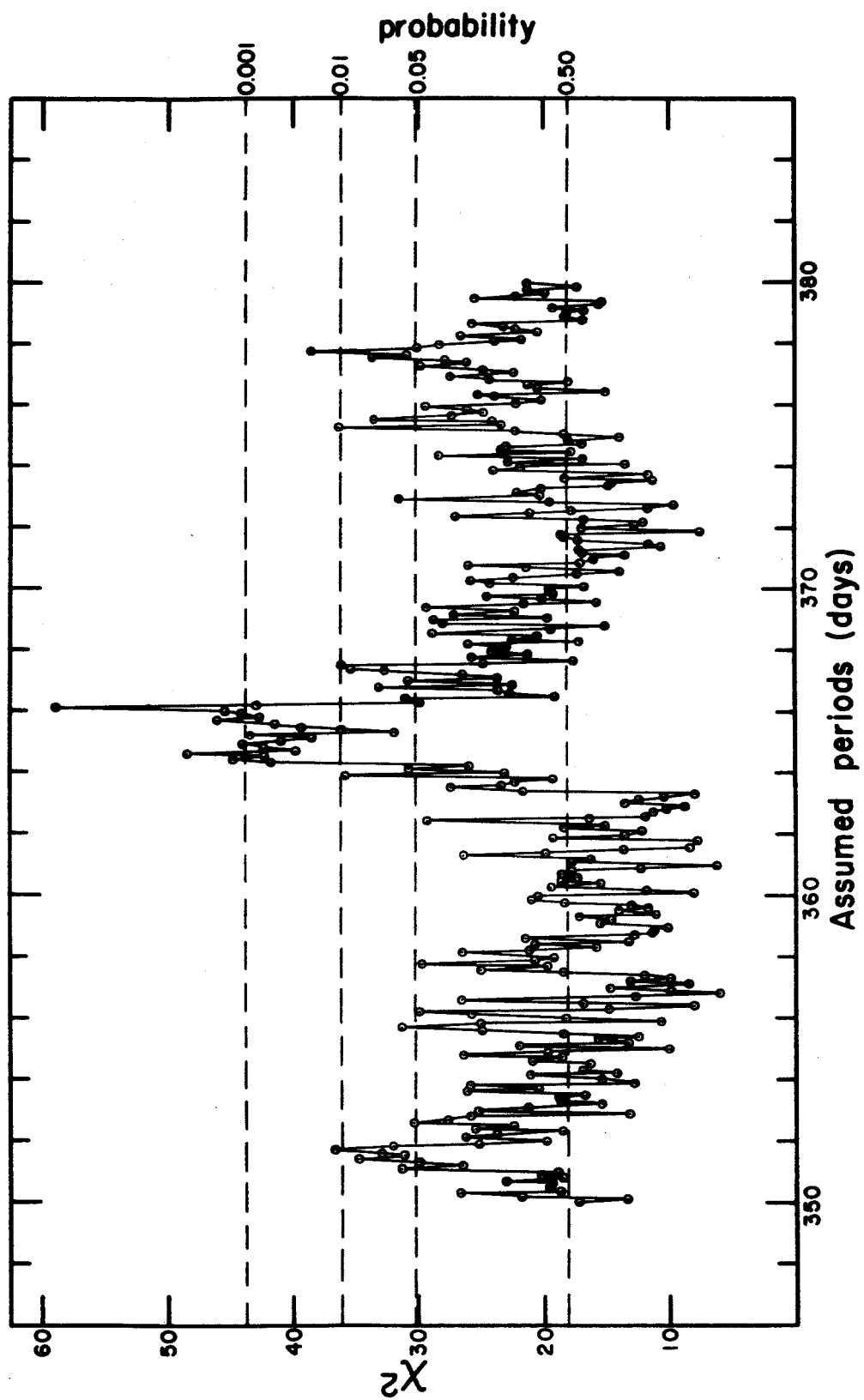


Figure 6

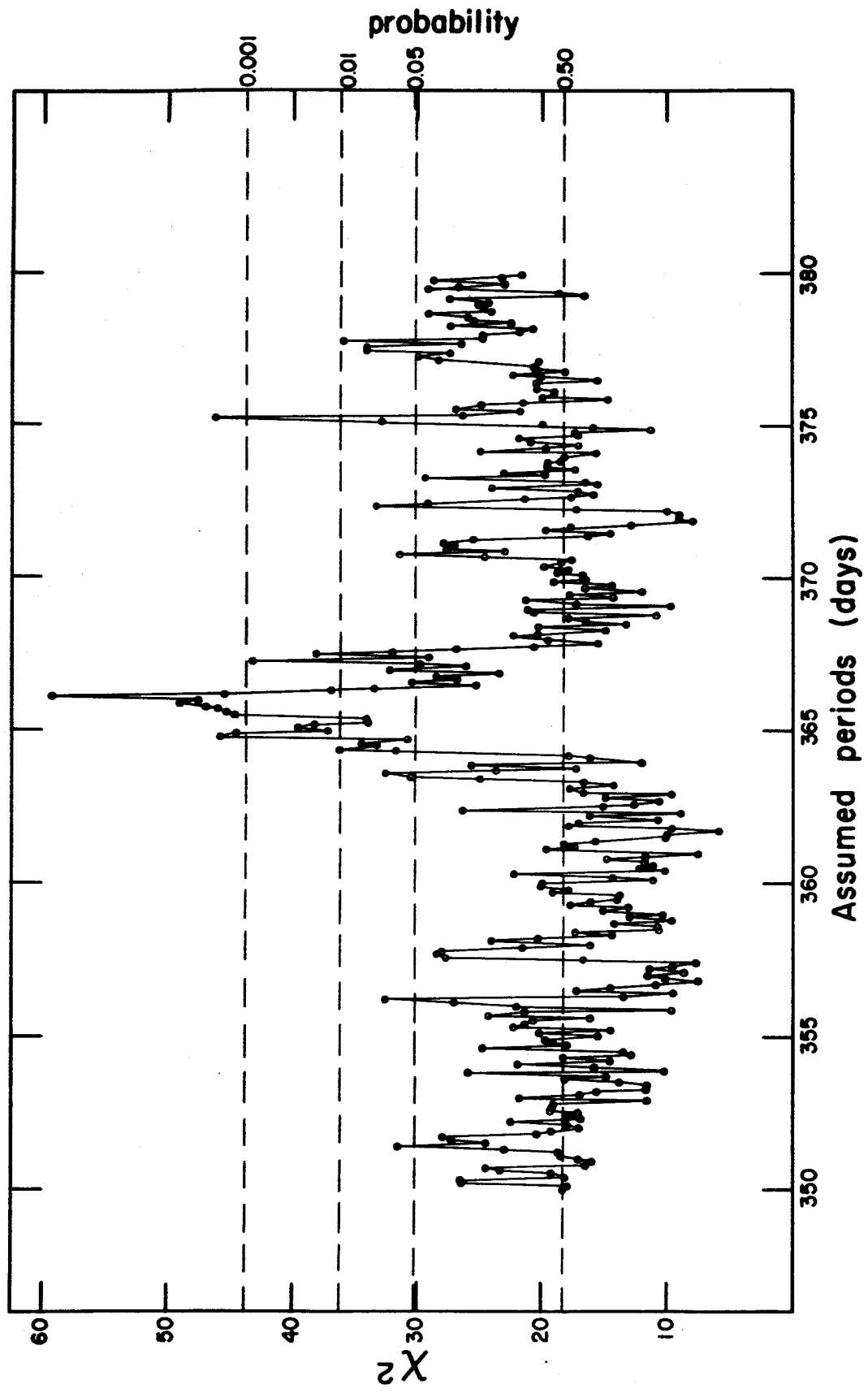


Figure 7

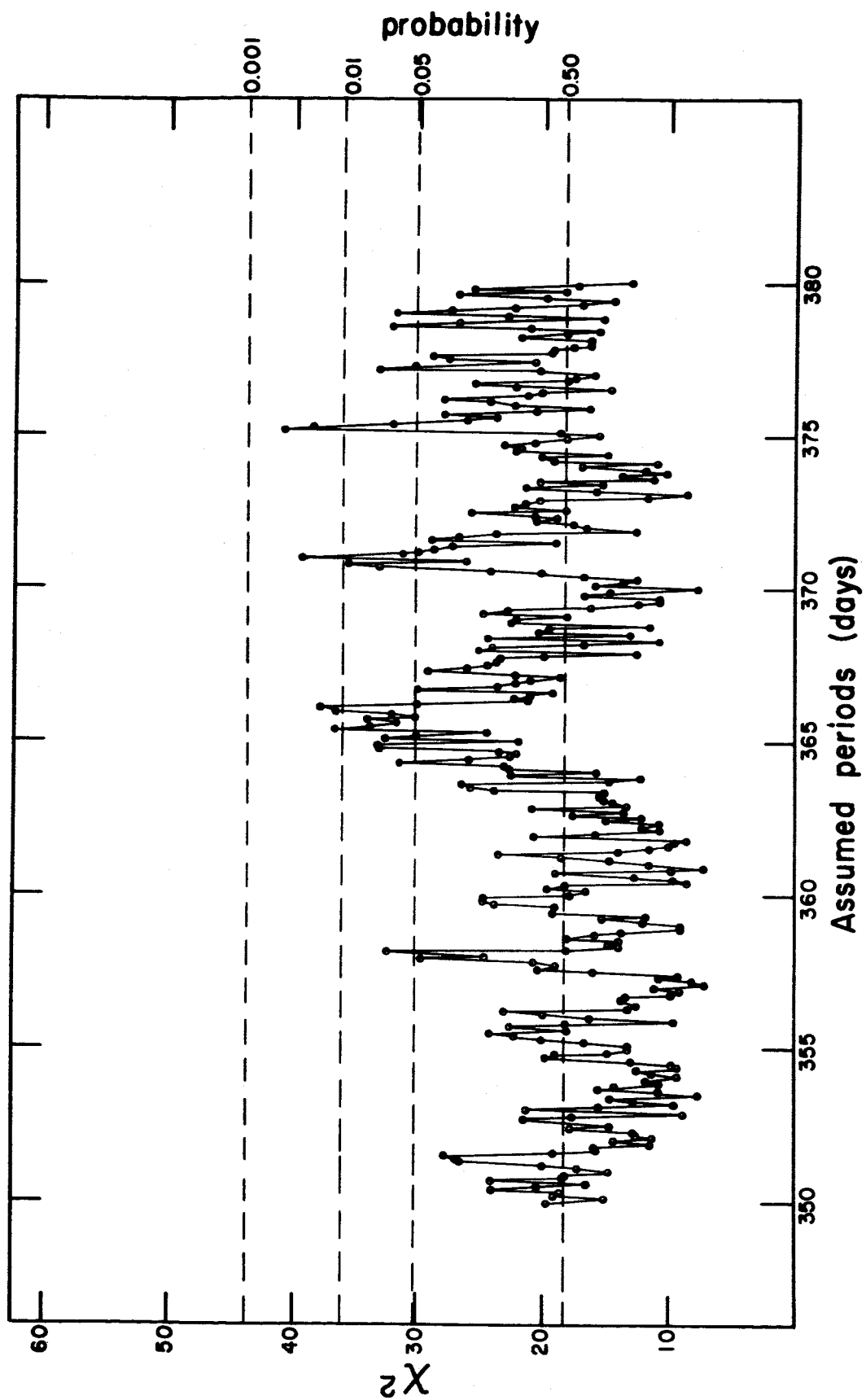


Figure 8

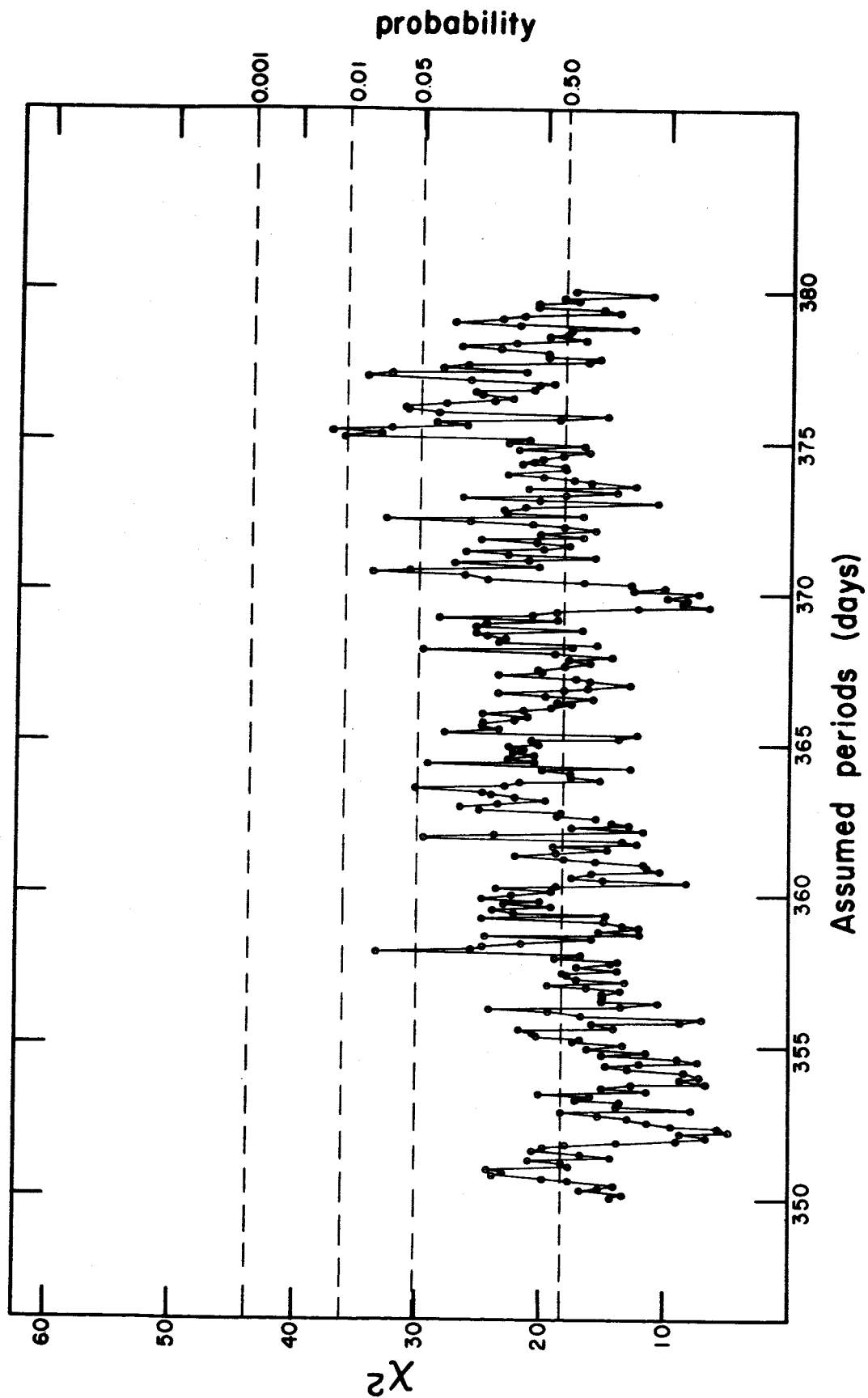


Figure 9

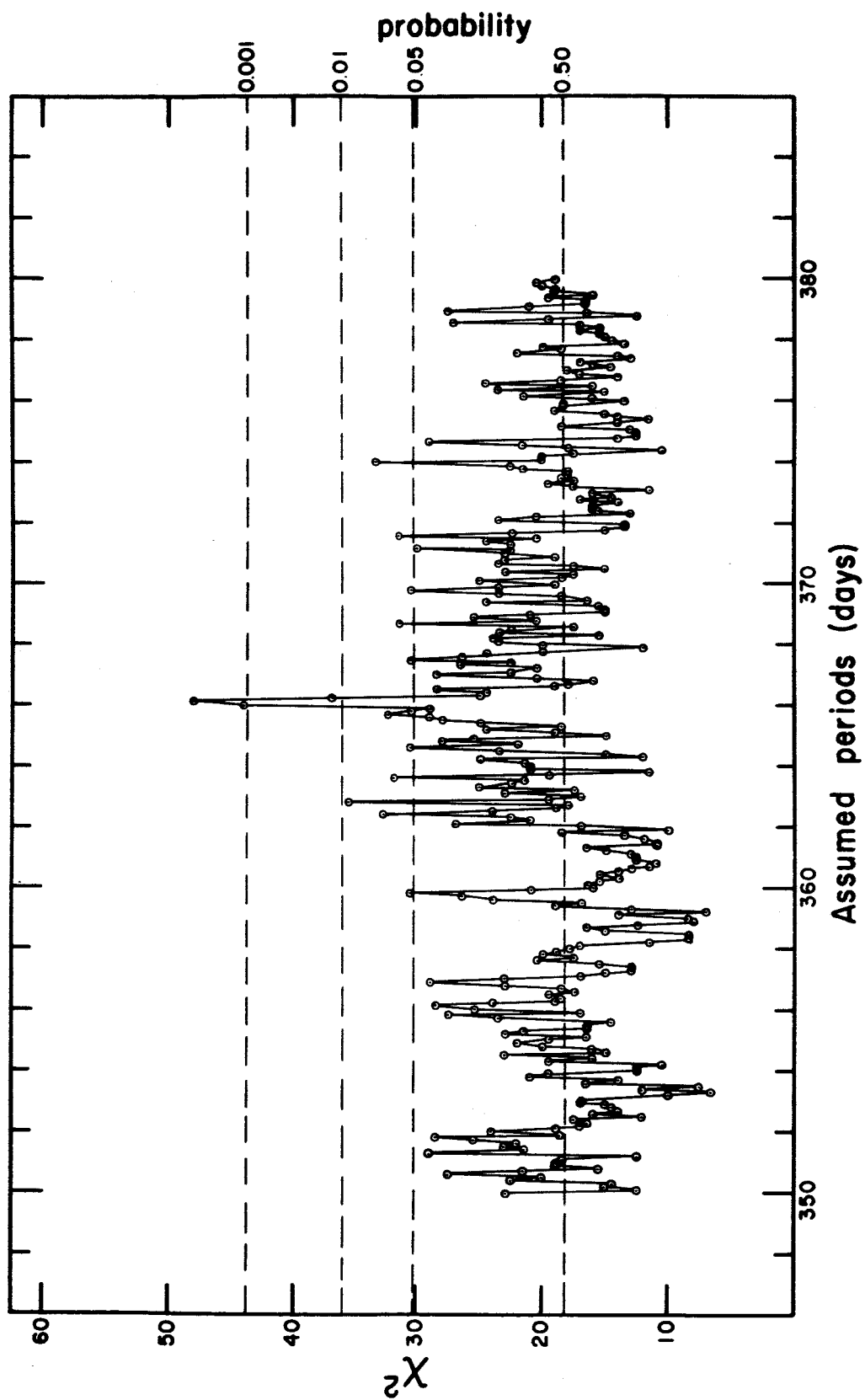


Figure 10

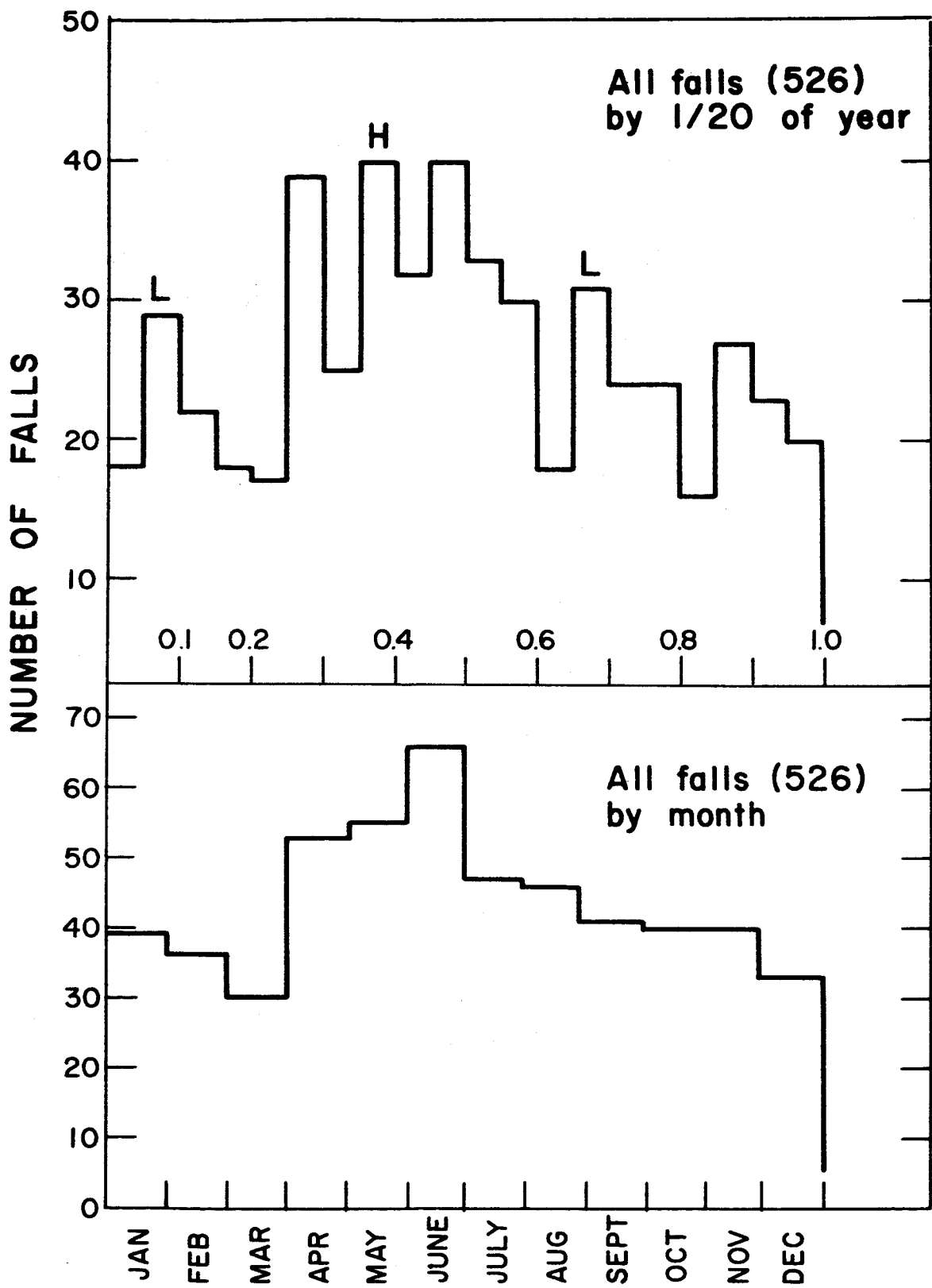


Figure 11

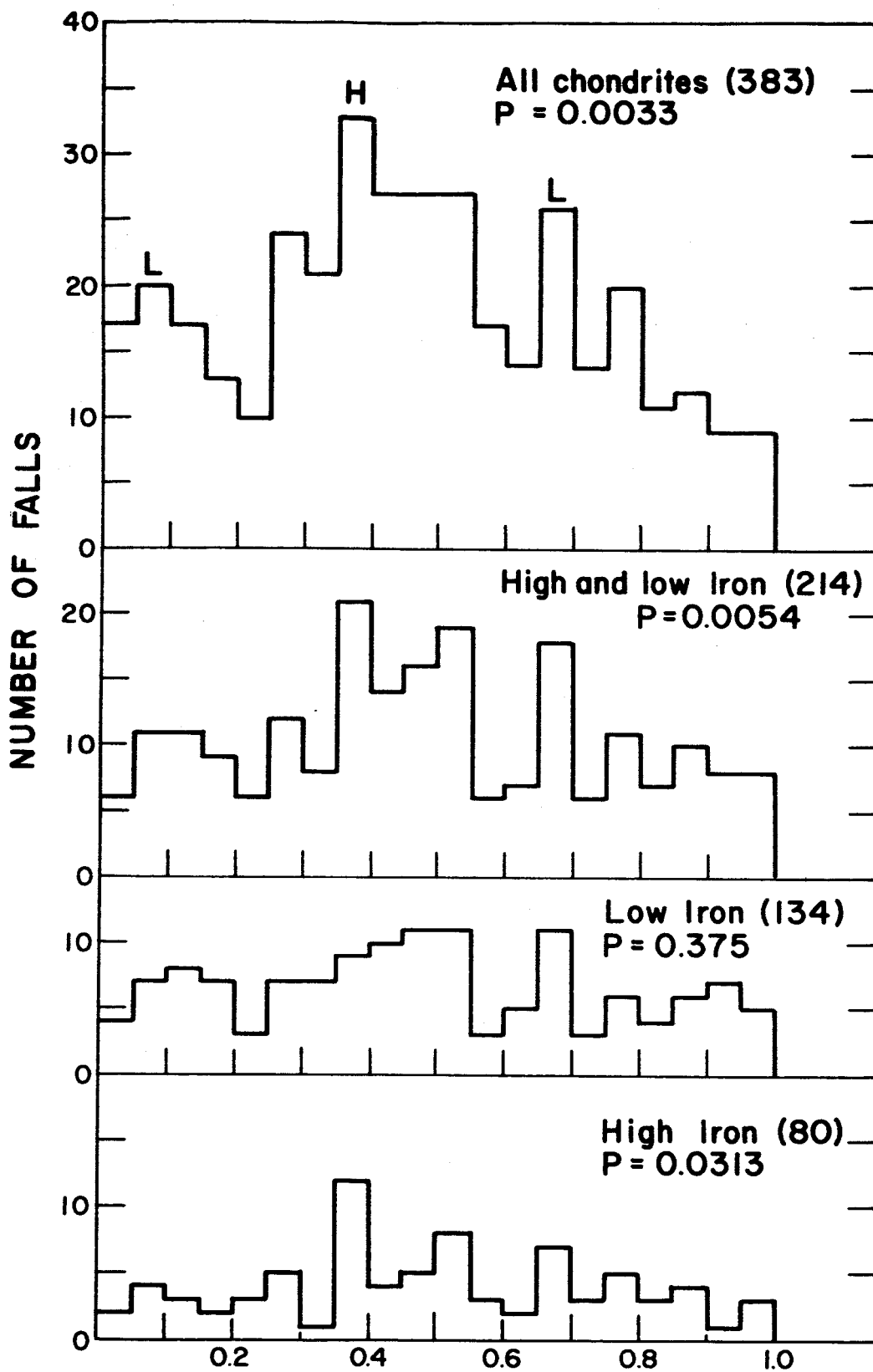


Figure 12

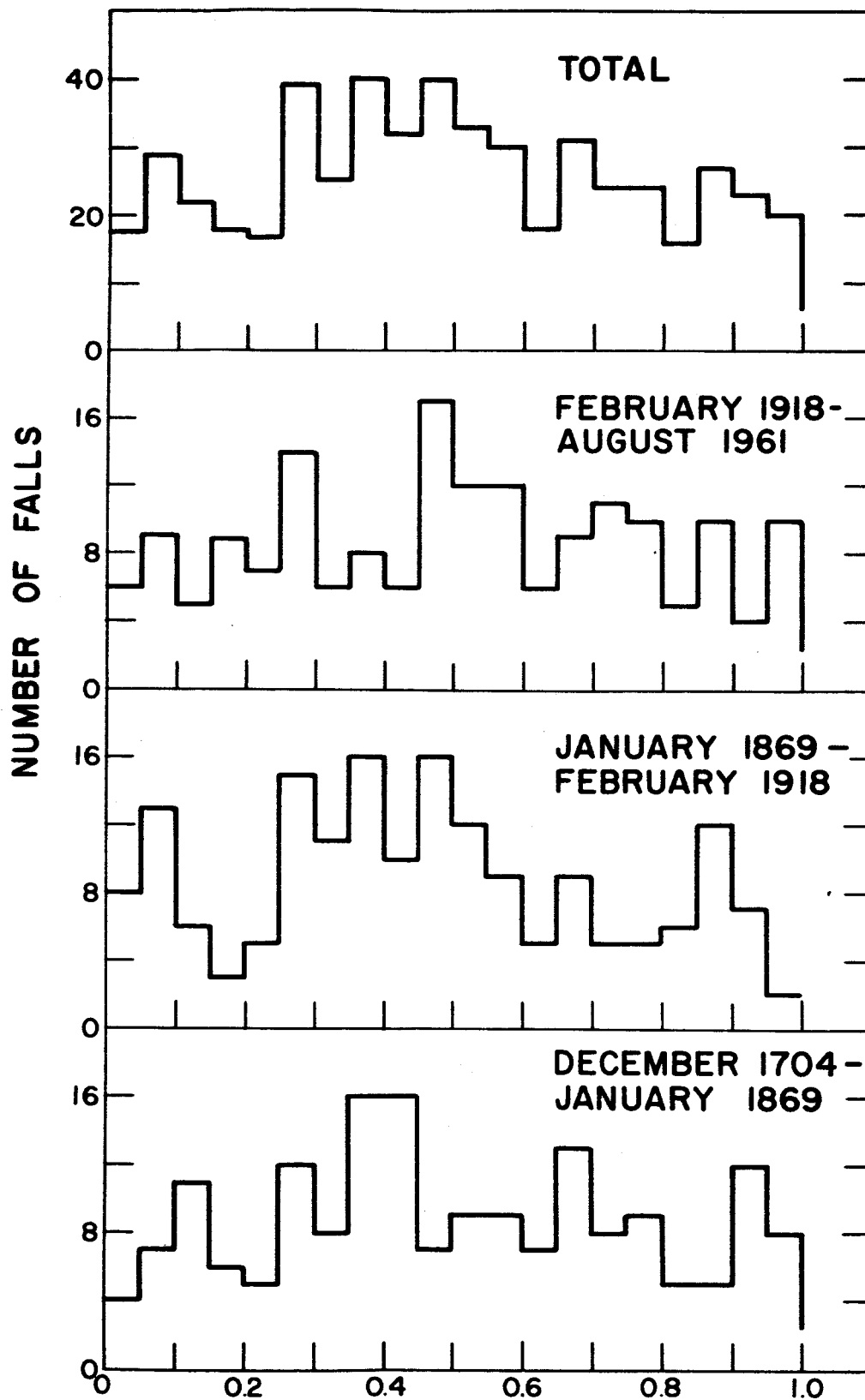


Figure 13

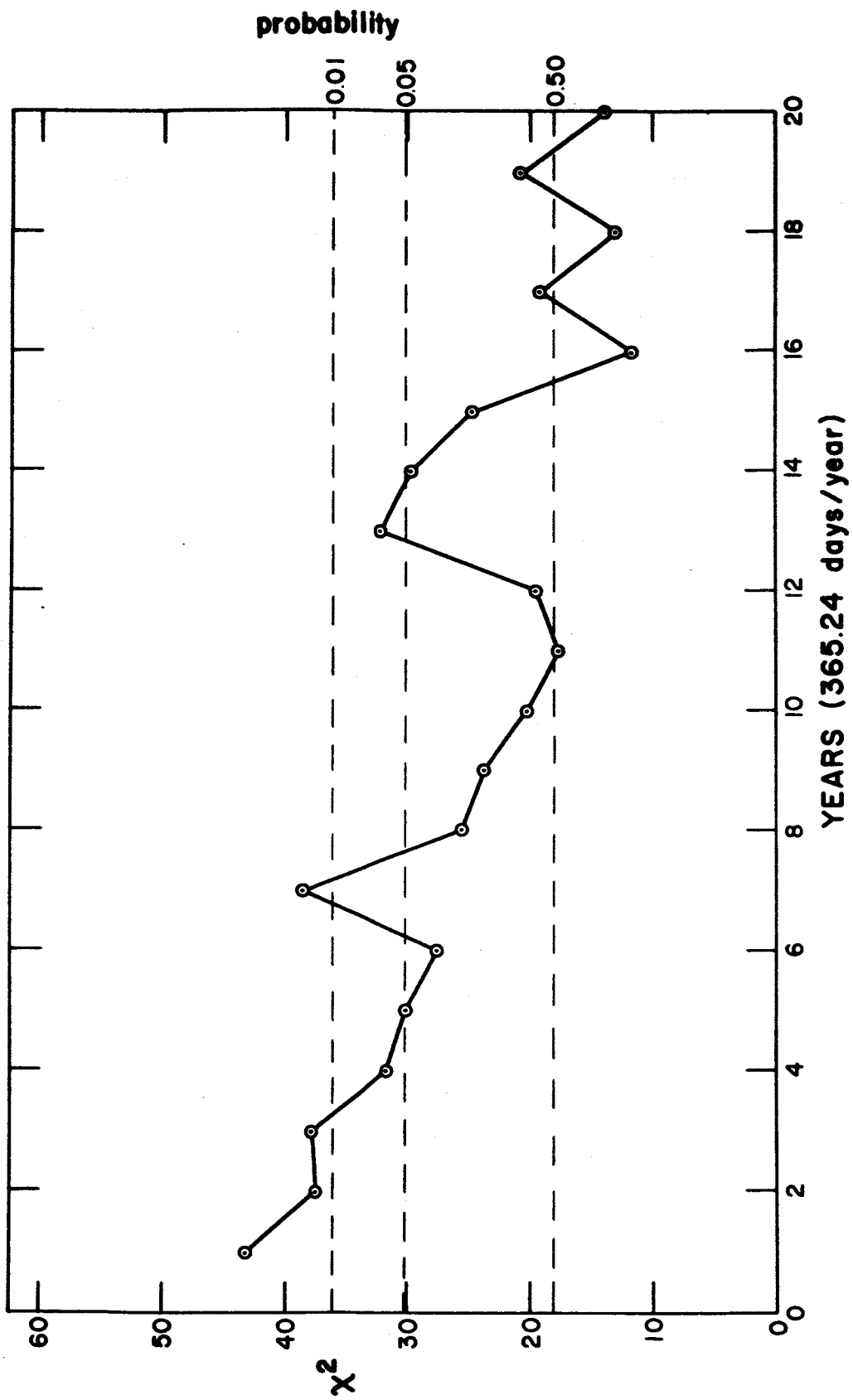


Figure 14

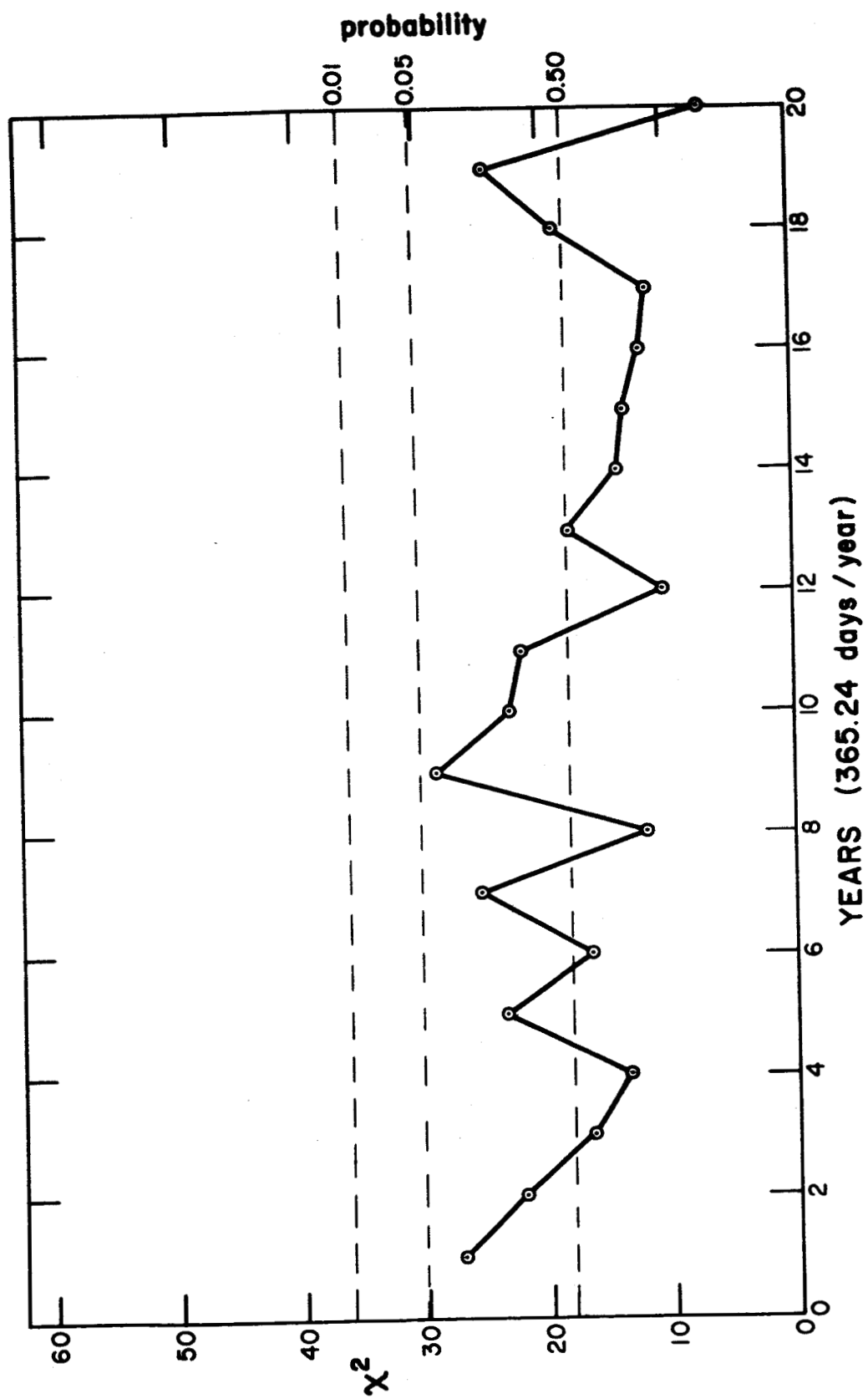


Figure 15

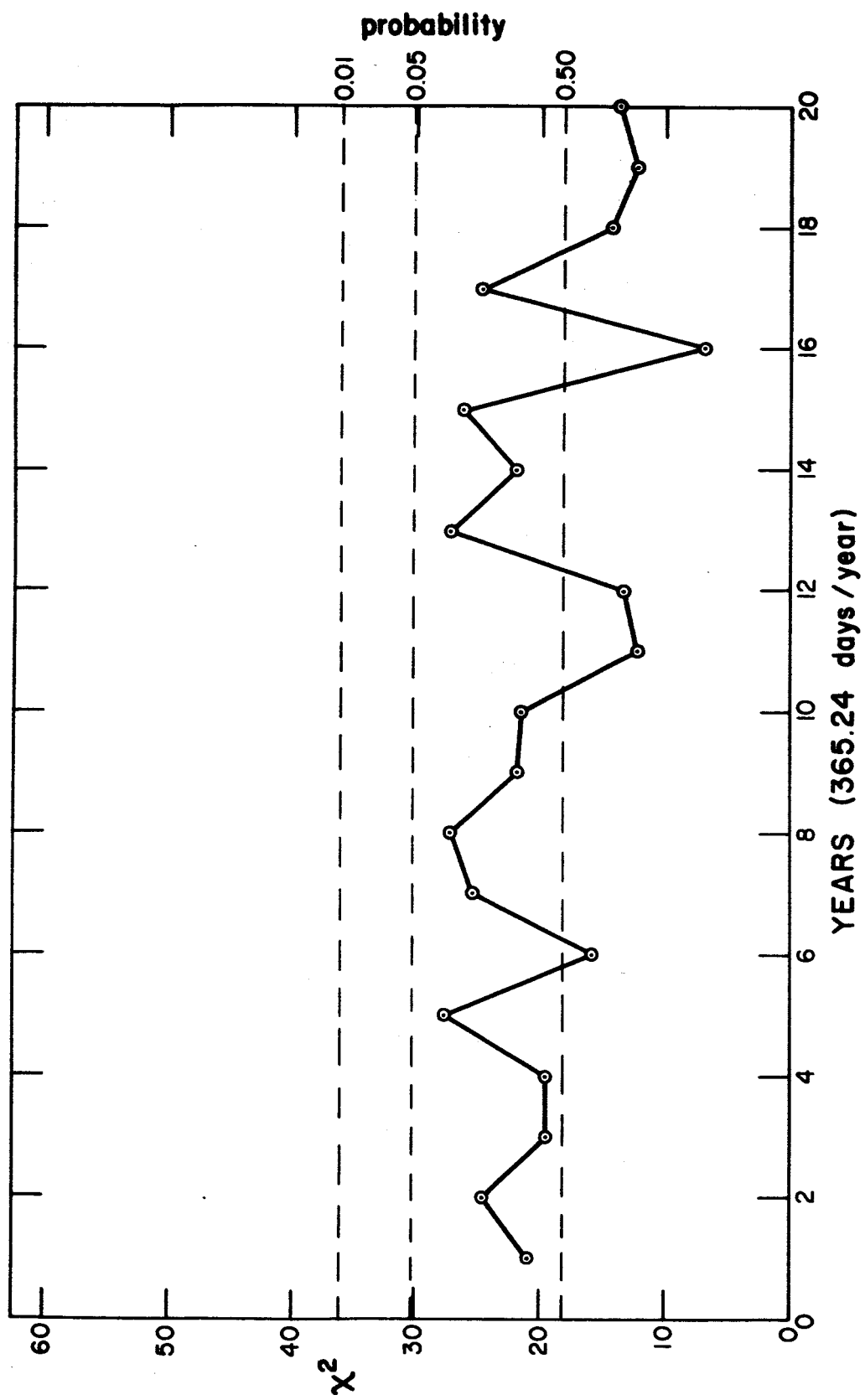


Figure 16

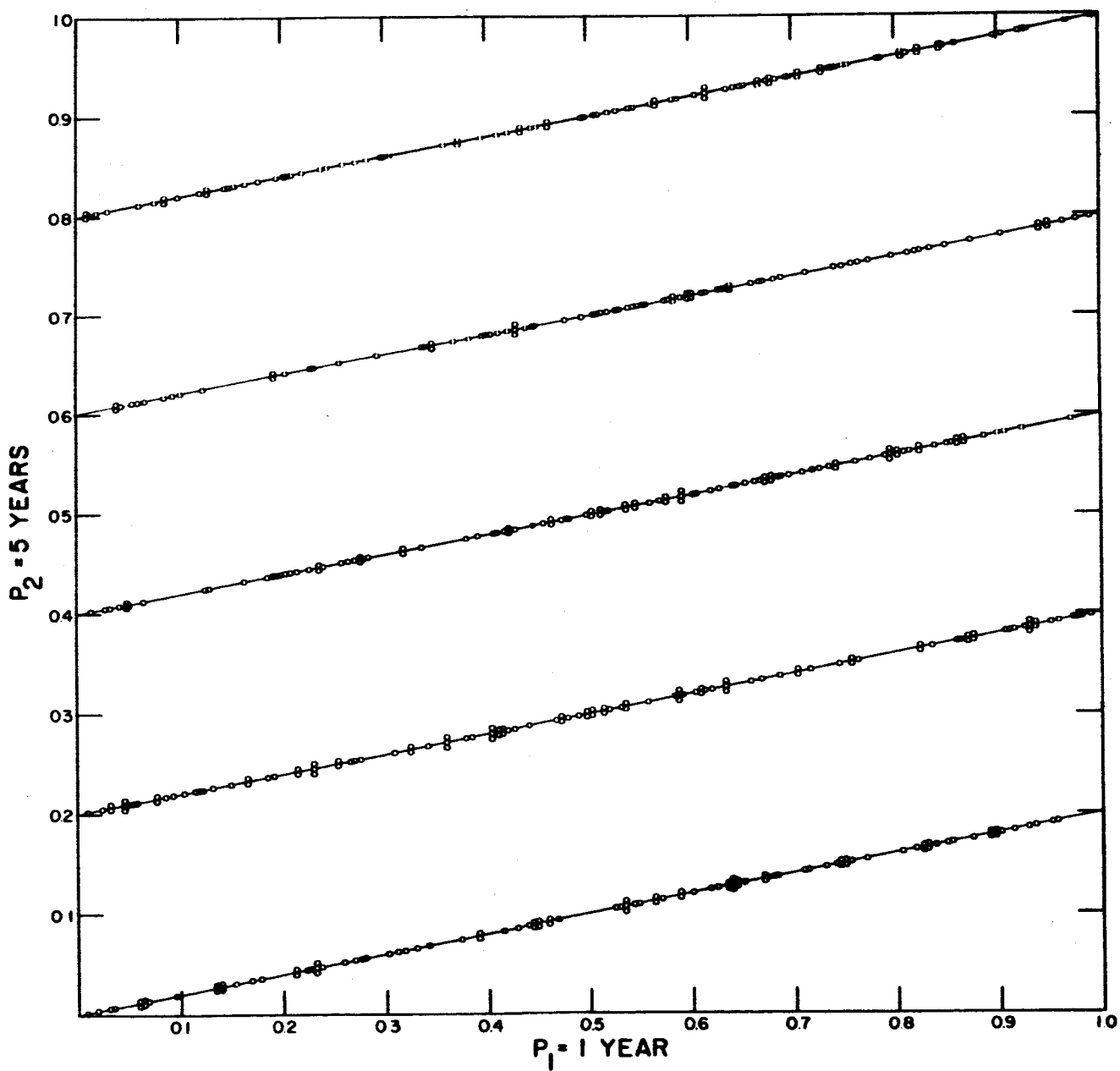


Figure 17

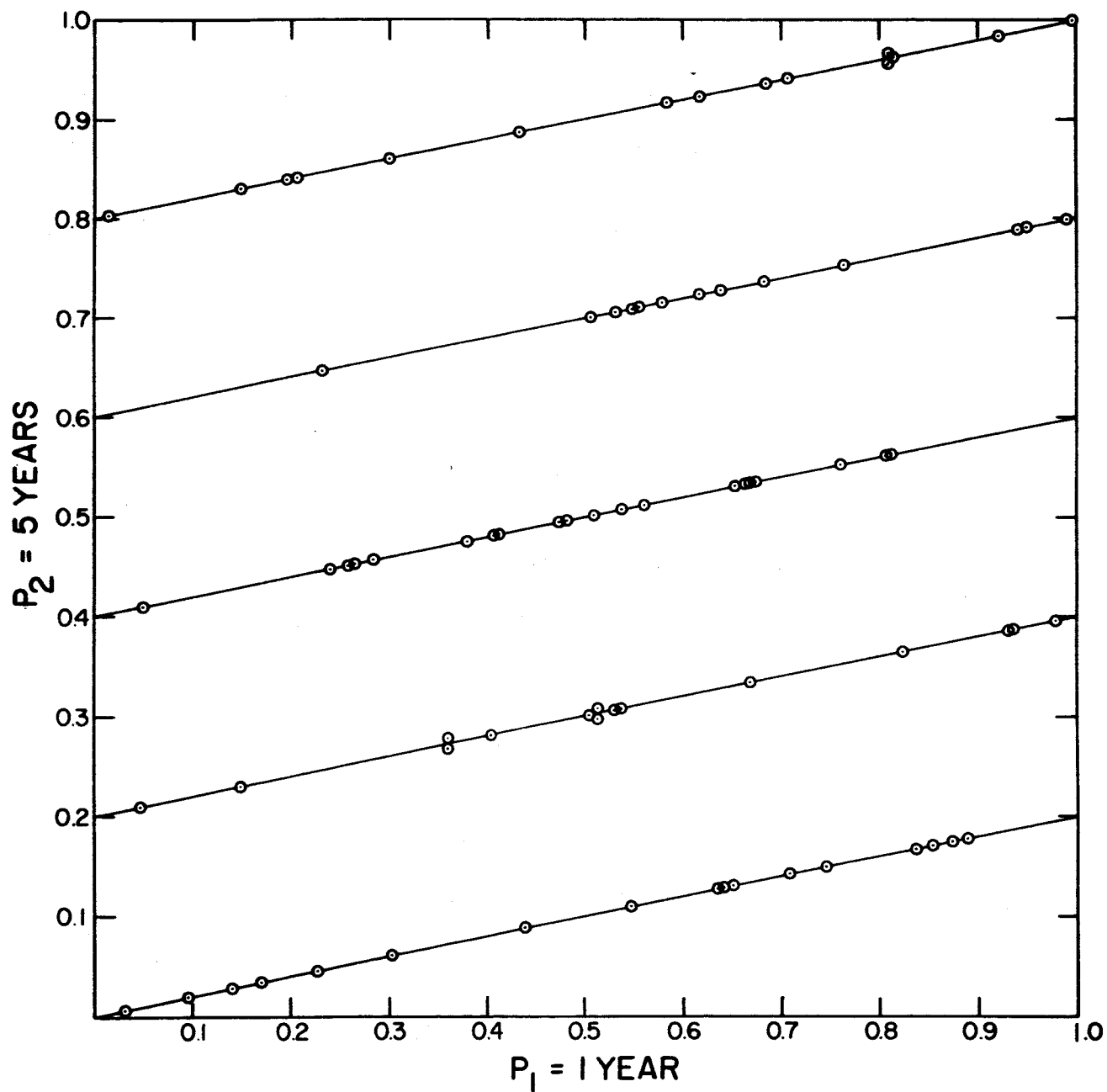


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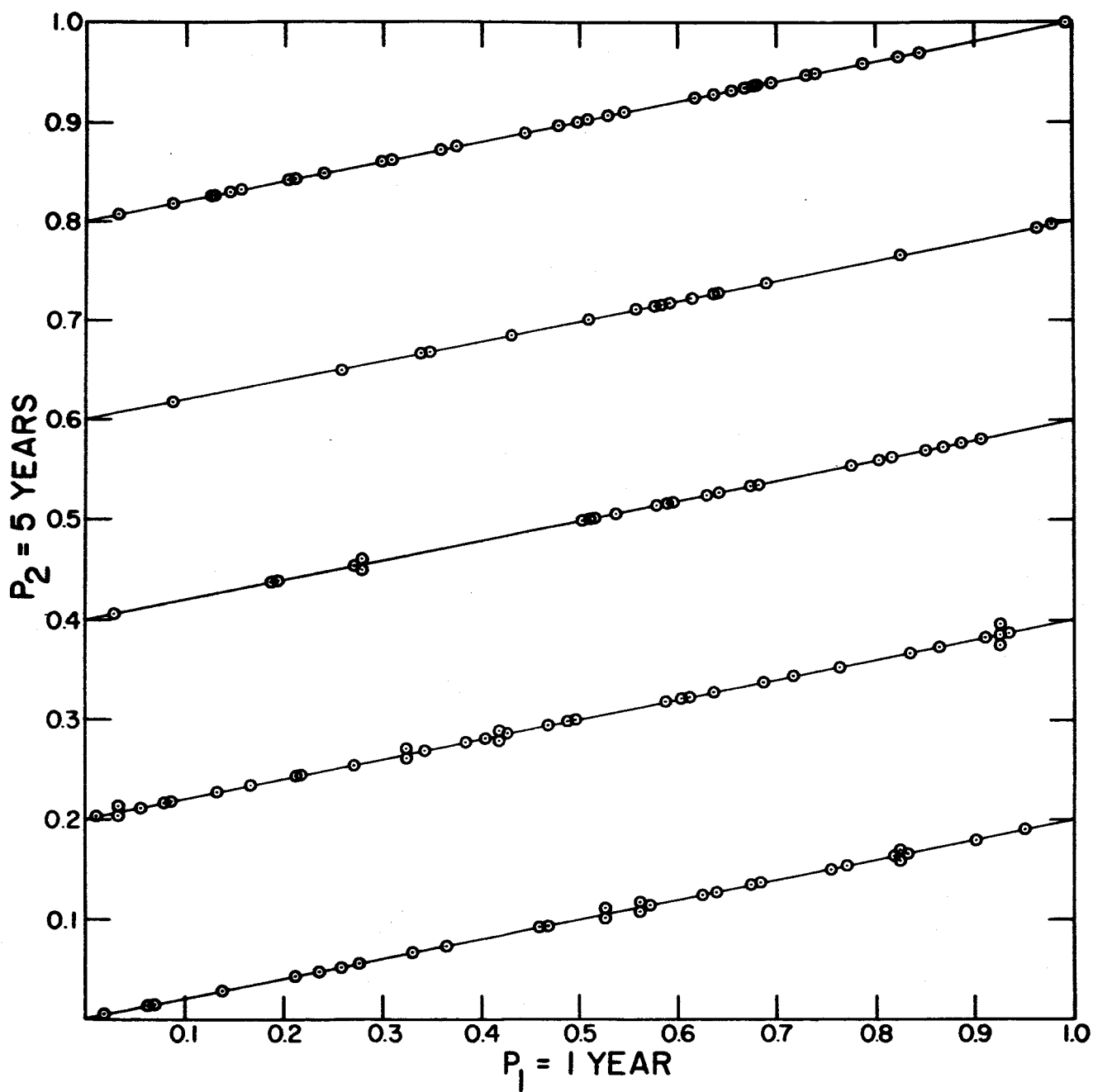


Figure 19

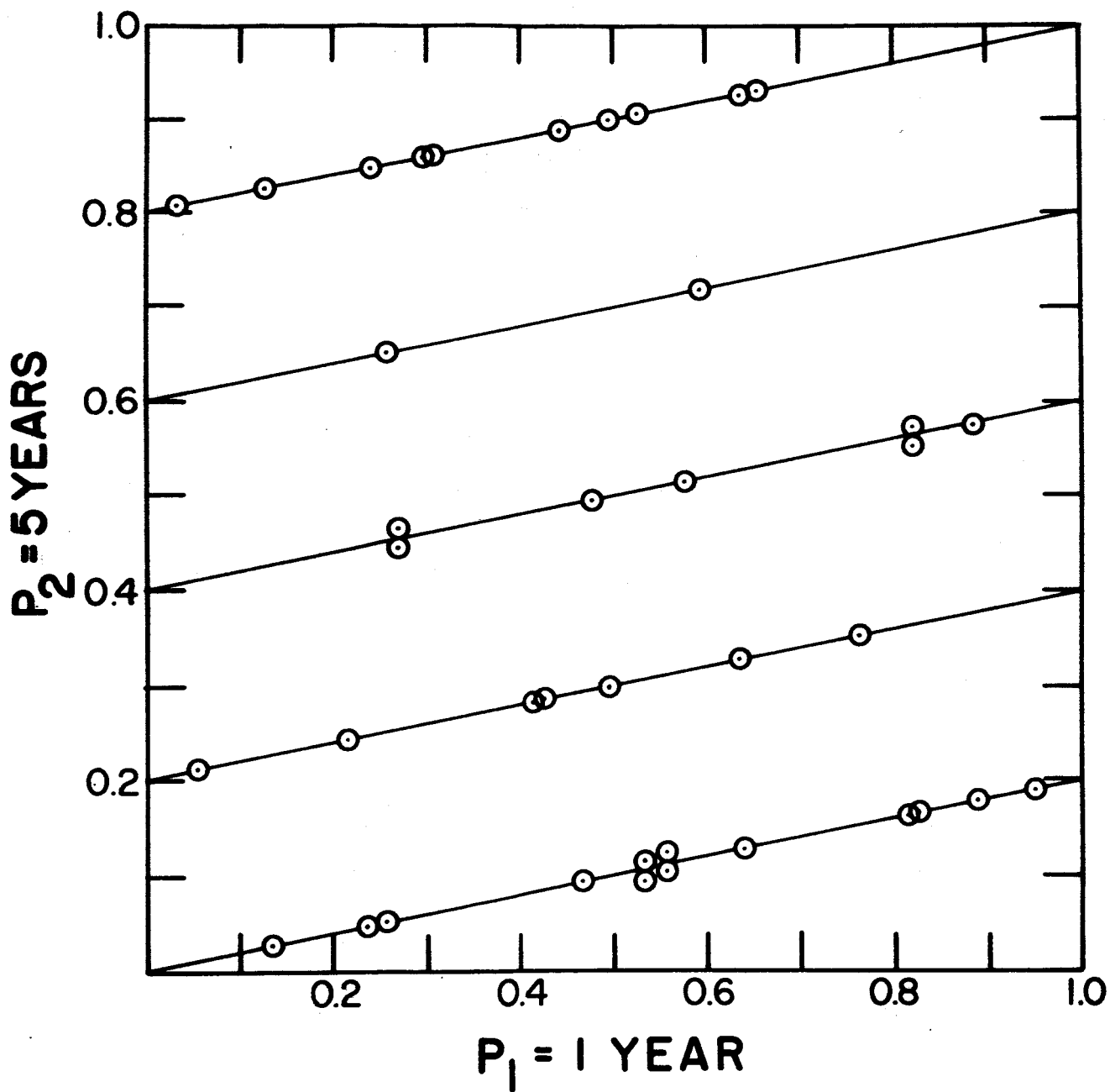


Figure 20